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**Research Paper
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Three-P Cubic Volume/Weight Scaling of Black Hills Sawtimber

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Abstract: As sawlog size decreases, weight scaling of logs from timber sales is an increasingly important alternative to stick scaling individual logs. Timber sales measured in board-foot/weight scale often results in highly variable ratios or conversion factors. Using a cubic foot/weight measure produces lower sampling variation.

For 2 timber sales in the Black Hills National Forest, three-P cubic foot scaling of ponderosa pine and white spruce required up to 68% fewer truckloads for scaling as compared with 3-P Scribner board foot scaling. This study also showed that, depending on the timber sale, ratio weights may require recalculation.

Keywords: cubic foot, 3-P, weight scaling, truckloads, *Pinus ponderosa, Picea glauca*

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Front cover: *Truckloads of logs are weighed at the sawmill and scaled by Forest Service scalers using the 3-P scaling method.*

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Three-P Cubic Volume/Weight Scaling of Black Hills Sawtimber

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Three-P Cubic Volume/Weight Scaling of Black Hills Sawtimber

by Donald C. Markstrom and Rudy M. King

INTRODUCTION

As sawlog size decreases, weight scaling of logs from timber sales is an increasingly important alternative to stick scaling individual logs. Timber sales measured in board foot scale, however, often result in highly variable board foot/weight ratios or conversion factors. Using a cubic foot measure instead of board foot measure produces lower sampling variation (Markstrom and King 1993). Consequently, scaling time and costs are lower when weight scaling with cubic volume than board foot volume.

In 1990, the Forest Service began pilot testing of cubic measure. The Forest Service Region 2 tested cubic scaling in the Black Hills and Rio Grande National Forests. The purpose of the study was to develop:

- Information about the volume/weight relationships of the timber to use in weight scaling, and
- Methods to accurately estimate truckload volumes based on truckload weights.

Results of the initial study indicate that cubic foot/weight scaling of ponderosa pine and white spruce on the Black Hills National Forest requires less than half the number of truckloads to be scaled as compared with the number required for Scribner board foot/weight scaling, allowing for a 2% sale-wide error (Markstrom and King 1993). This reduction in the number of loads to be sampled reduces scaling time and costs. Cubic foot/weight scaling of Engelmann spruce and white fir logs in the Rio Grande National Forest resulted in 19% fewer loads scaled as compared with the number required for Scribner board foot/weight scaling. This study shows that ratio weights require recalculation depending upon changes in timber size and woods storage time. Tree age/size, woods storage time of logs, number of logs per truckload, percentage of cubic volume in defect, and the amount of substandard material in a load affect the ratio weights.

During this initial study, it was impossible to compare the results from the 3-P sampling method with the conventional sampling method because the variances of the two methods were not homogeneous. Consequently, only logs scaled by the conventional method were analyzed. The conventional sampling method measures every log on sample truckloads, while the 3-P sampling method measures only sample logs on sample truckloads.

This paper addresses the question:

How does cubic scaling compare with Scribner board foot scaling when only 3-P sampling methods are used?

The objectives of this study were to:

- Test the feasibility of 3-P cubic foot/weight scaling of truckloads of logs, and
- Identify and evaluate sources of variation that may affect the reliability of weight scaling.

METHODS

A total of 69 truckloads of ponderosa pine and white spruce logs were sampled in the Black Hills National Forest. Twenty-two loads were from the Prospect Timber Sale, 26 loads from the Ridge Timber Sale, and 21 loads from the Board Timber Sale. The sale areas were in the Spearfish Ranger District in the northern Black Hills.

The truckloads of logs were weighed at the sawmill and scaled by Forest Service scalers using the 3-P scaling method for both cubic and Scribner volumes.[1] All logs on each truckload were counted and scaled for gross volume and defect. Single

[1] *Forest Service Log Scaling Handbook 2409.27-3P.*

segment short logs were scaled, the longest log was 18.0 ft. Both diameters of the sample logs were measured. Butt logs were measured 4.0 ft from the butt end with a caliper. Cubic volumes were determined with Smalian's formula. Logs scaled to a 7.0 in top were considered standard material; however, the purchasers hauled some logs with top diameters of 4.0 in. The cubic volume of this substandard material with top diameters between 7.0 to 4.0 in was scaled and recorded for each truckload (table 1). All logs were hauled and weighed concurrently with felling and skidding.

Several statistical methods were used to identify and analyze factors that affected the accuracy of the volume/weight predictions. Scatter diagrams were prepared to compare truckload volume with load weight and number of logs on the loads for each sale. Analysis of variance was used to compare response variables among the timber sales. Regression models to predict truckload volume were developed and compared with each other. An application of a model to determine the number of sample truckloads is presented in the results and discussion.

Table 1. Average percent defect of the logs for each sale.

Sale	Cubic scale	Scribner scale
Prospect	6.9	10.1
Ridge	7.0	10.9
Board	6.1	9.7

RESULTS AND DISCUSSION

Plotting of truckload volume and weights for the logs from each sale (figs. 1 through 3) indicated that volumes of truckloads may vary considerably for a given truckload weight. Paired data points of net cubic volume of logs with load weights and number of logs were scattered differently for the Prospect Sale than for either the Ridge or Board Sales. Apparently, the truckloads were from 2 or more populations in the Prospect Sale. Possible explanations were that the trucks were loaded to an approximate target weight with logs from either small young trees or large old trees, or were loaded with logs of different species mix. Small young

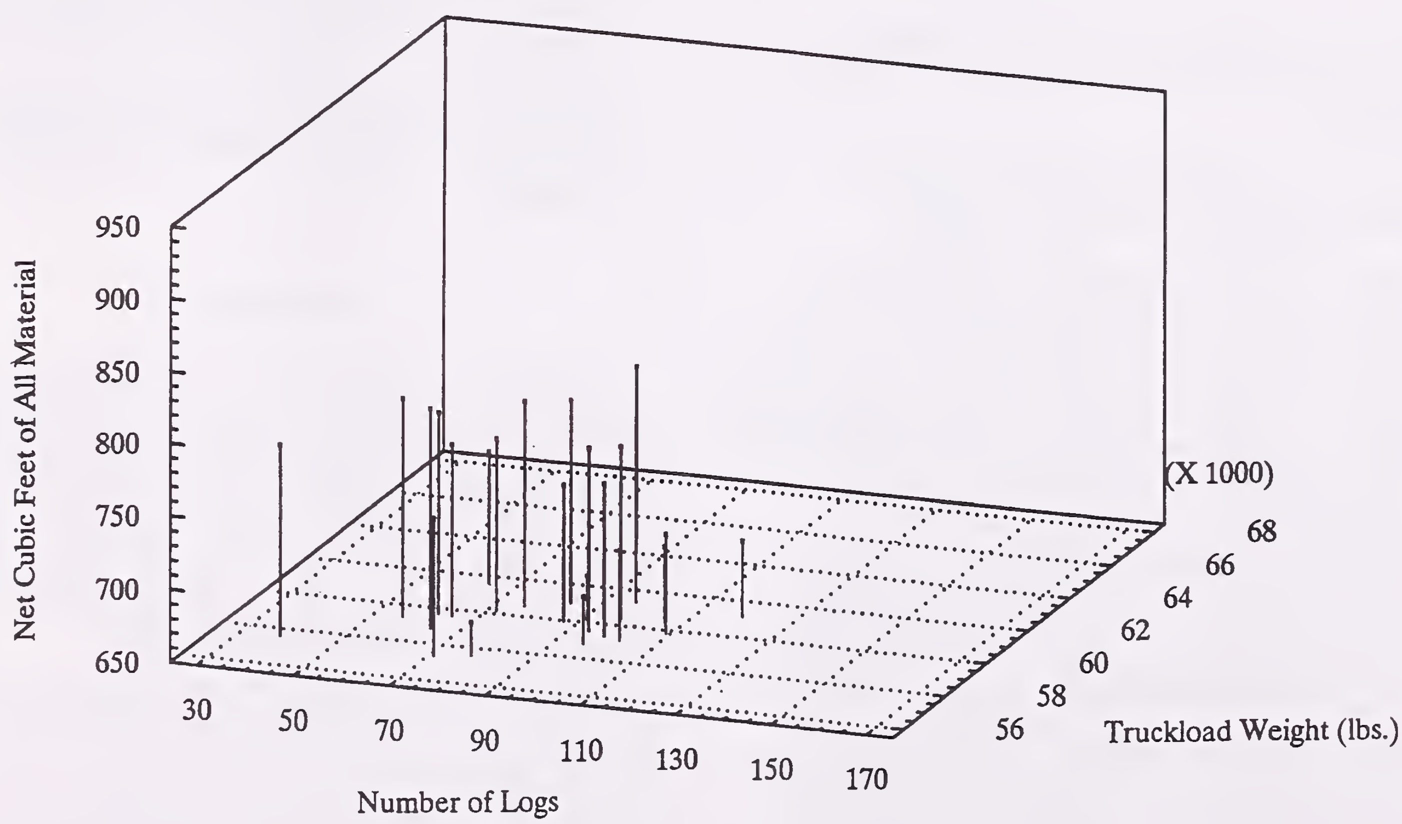

Figure 1. Scatter diagram of net cubic feet of all material versus truckload weight and number of logs for the Prospect Timber Sale.

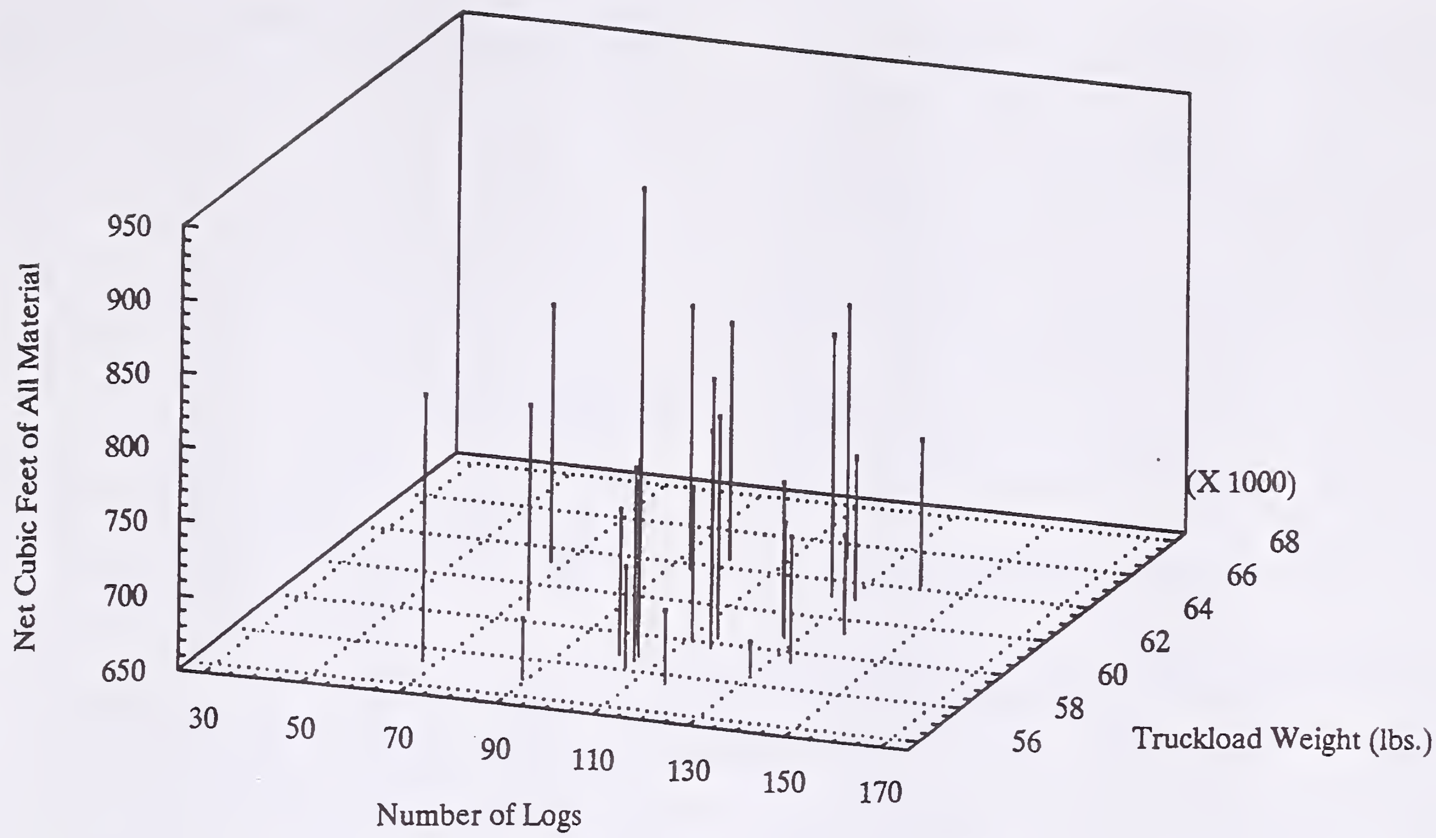

Figure 2. Scatter diagram of net cubic feet of all material versus truckload weight and number of logs for the Ridge Timber Sale.

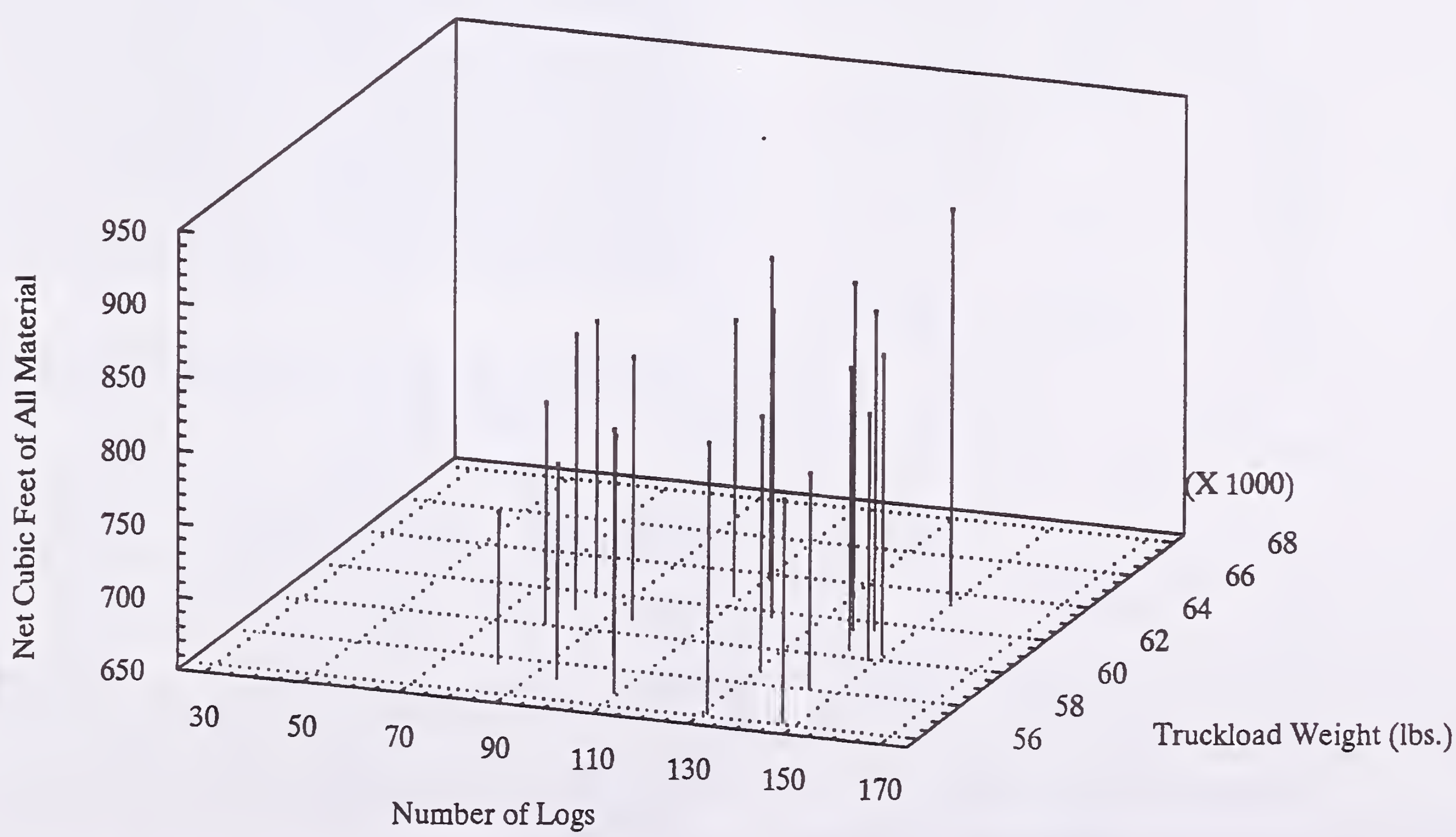

Figure 3. Scatter diagram of net cubic feet of all material versus truckload weight and number of logs for the Board Timber Sale.

trees may have a lower wood volume per unit of weight than old large tree because of high sapwood and water content in the young trees. Specific gravity of wood with green moisture conditions for ponderosa pine is listed as 0.38 and for white spruce as 0.33 (Wood Handbook 1987). The Prospect Sale also had a narrower range of truckload weights than either the Ridge or Board Sales.

Further data analysis was limited to the 47 truckloads of the Ridge and Board Timber Sales. Additional analysis on the Prospect sample was not performed because there was little predictability in the data (fig. 4).

The particular timber sale affected the ratio weights of net cubic feet per pound (CF/lb) of all material to a 4-in top and net Scribner board feet per pound (BF/lb) to a 7.0-in top. The Board Timber Sale had a higher CF/lb and BF/lb than the Ridge Sale (table 2). The reason for the difference of the ratio weights between the two sales was not apparent.

Four regression models were used to estimate truckload volume, each was estimated with and without an intercept. All models included truckload weight as a predictor. The number of logs and substandard logs were also included to assess their added prediction capability. The four models were:

$$\hat{V} = b_0 + b_1 W \qquad (1)$$

$$\hat{V} = b_0 + b_1 W + b_2 l \qquad (2)$$

$$\hat{V} = b_0 + b_1 W + b_3 l_S \qquad (3)$$

$$\hat{V} = b_0 + b_1 W + b_2 l + b_3 l_S \qquad (4)$$

where:

$\hat{V}$ = estimated truckload net cubic foot or net board foot volume
W = weight of logs on truck
l = number of logs on the truckload
l_S = number of substandard logs on the truck
b_0, b_1, b_2 and b_3 = regression coefficients.

Table 3 summarizes regression equations obtained by fitting the 4 equations to 2 data sets:

- Net cubic-foot volume of all material including substandard material to a 4-in top (CF-VOL), and
- Net Scribner board foot volume to a 7-in top (BF-VOL).

The R^2 statistic showed the proportion of variation explained by each equation. The standard error of estimate (SE) measured how precisely the regression equation predicted volume with mean weight (and number of logs). The standard errors were only comparable within each dependent variable group. Comparison of R^2 and SE values between regressions indicated that counting the logs will generally improve the prediction of truckload

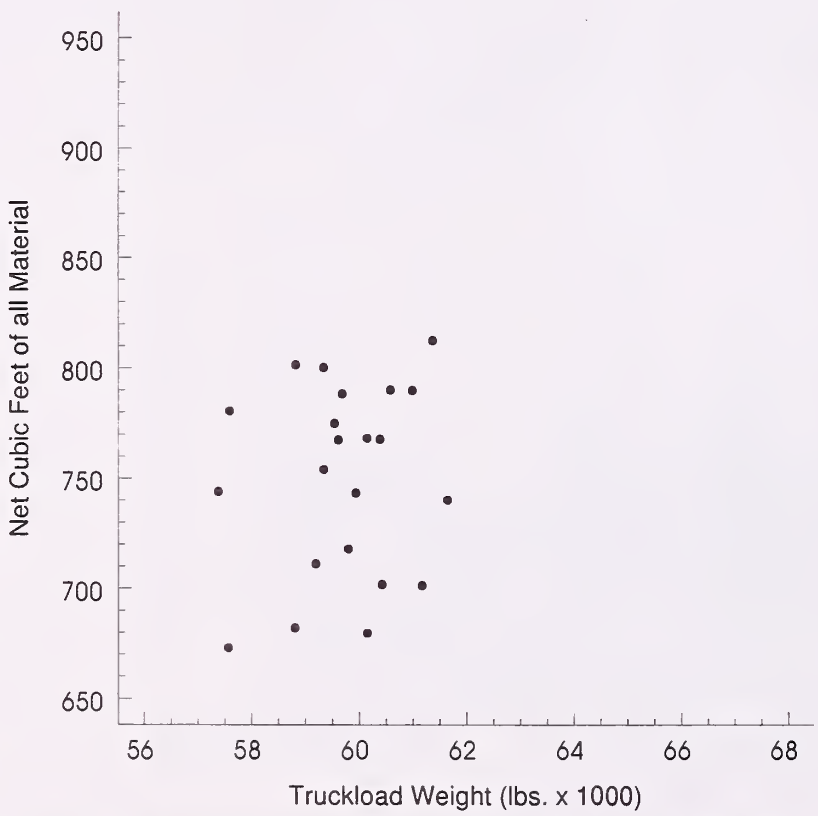

Figure 4. Scatter diagram of net cubic feet of all material versus truckload weights for the Prospect Timber Sale.

Table 2. Ratio weights of (CF/lb) and BF/lb of different timber sales.[1,2]

Timber sale	CF/lb Mean + 1 Std. Dev	BF/lb Mean + 1 Std. Dev
Ridge	.0126 + .0007	.0641 + .0078
Board	.0139 + .0004	.0679 + .0030

[1] *Where 1) CF/lb = net cubic feet per pound of all material, and 2) BF/lb = net Scribner board foot volume per pound to a 7.0 in top.*

[2] *Values between timber sales are significantly different at p<.05.*

volume. However, because counting logs on a truckload during weighing is cumbersome and costly, it is generally not practiced. The pragmatic value of prediction improvement by counting logs is often less than the cost of counting the logs.

All regression equations in table 3 consistently showed the inverse relationship (b_3) between load volume and number of logs with substandard material. The inverse relationship (b_2) between load volume and number of logs was inconsistent depending on the particular regression equation (table 3). The volume of a truckload may decrease as the number of logs and/or number of logs with substandard material increases. Small logs tend to have higher moisture and higher weight per cubic foot than large logs (Landt and Woodfin 1959).

Analysis of prediction equations with truckload weight alone (table 3, equation 5) indicated that the Ridge Timber Sale and the Board Timber Sale each had significantly different ($P<.001$) equations as determined by the extra sum of squares principle (Draper and Smith 1981). Consequently, different regression equations were determined for each timber sale. The constant term in the equations were not significantly different from zero ($P>.30$). The equation $\hat{V} = b_1 W$ can be used to determine truckload volume. This equation, without constant term, is used in ratio-weight scaling.

Table 3. Summary of regression coefficients (b_0, b_1, b_2, b_3), coefficients of determination (R^2) and standard errors of estimate for 8 equations applied to 2 timber sales for truckloads of Black Hills ponderosa pine log and white spruce. The dependent variables are CF-VOL and BF-VOL[1].

Dependent variable[2]	Sale and equation number	Number of loads	Regression coefficients b_0	b_1	b_2	b_3	Coeff. of determ. R^2	Standard error of est SE
CF-VOL	**Ridge**							
	1	26	NS[3] 76.6	.0114			.36	41
	2	26	NS 198.9	.0116	-1.2307		.64	31
	3	26	NS 87.1	.0117		-4.6749	.67	30
	4	26	NS 137.0	.0117	NS -.5364	NS -3.1529	.69	30
	5	26		.0126			.35	40
	6	26		.0147	-1.1536		.61	32
	7	26		.0131		-4.6646	.66	30
	8	26		.0137	NS -.4104	-3.4956	.68	30
CF-VOL	**Board**							
	1	21	NS 158.6	.0112			.52	26
	2	21	NS 86.9	.0112	.6087		.71	21
	3	21	NS 166.3	.0111		NS -1.8494	.52	26
	4	21	NS 105.1	.0103	.9932	-15.2119	.85	15
	5	21		.0139			.49	26
	6	21		.0126	.6311		.70	20
	7	21		.0139		NS -1.0330	.49	26
	8	21		.0120	1.0147	-14.9907	.84	15

Table 3. Cont'd.

Dependent variable[2]	Sale and equation number	Number of loads	Regression coefficients b_0	b_1	b_2	b_3	Coeff. of determ. R^2	Standard error of est SE
BF-VOL	Ridge							
	1	26	NS 4392.2	-.0082			<.01	450
	2	26	NS 4343.3	NS -.0082	NS .4924		<.01	459
	3	26	NS 4422.8	-.0073		NS -13.5449	.04	452
	4	26	NS 3561.2	NS -.0069	NS 9.2644	NS -39.8330	.11	443
	5	26		.0639			<.01	480
	6	26		.0600	NS 2.1766		<.01	487
	7	26		.0652		NS -13.0235	<.01	483
	8	26		.0467	NS 12.5396	NS -48.7424	<.01	460
BF-VOL	Board							
	1	21	NS -127.5	.0700			.45	182
	2	21	NS -76.6	.0700	NS -.4321		.46	187
	3	21	NS -64.9	.0691		NS -15.0079	.46	186
	4	21	NS -60.0	.0692	NS -.0799	NS -13.9332	.46	192
	5	21		.0679			.45	178
	6	21		.0688	NS -.4518		.46	182
	7	21		.0681		-15.3265	.46	181
	8	21		.0683	NS -.0921	NS -14.0594	.46	186

[1]Eight regression equations were used to estimate truckload volumes. Two equations used only truckload weights to estimate volume, another 2 used truckload weights and number of logs on the load, another 2 used truckload weights and number of substandard logs on load, and another 2 used truckload weights, number of logs on load, and number of substandard logs on load.

[2]Where:1) CF-VOL=net cubic foot volume of all material to a 4.0 in top and 2) BF-VOL=net Scribner board-foot volume to a 7.0 in top.

[3]NS values are not significant at p=.05.

The 8 equations were:

1) $v = b_0 + b_1 W$
2) $v = b_0 + b_1 W + b_2 L$
3) $v = b_0 + b_1 W + b_3 L_S$
4) $v = b_0 + b_1 W + b_2 L + b_3 L_S$
5) $v = b_1 W$
6) $v = b_1 W + b_2 L$
7) $v = b_1 W + b_3 L_S$
8) $v = b_1 W + b_2 L + b_3 L_S$

Where: v = *estimated truckload net cubic foot or net Scribner board foot volume,*
W = *weight of logs on truck*
L = *number of logs on truck*
L_S = *number of substandard logs on truck*
b_0, b_1, b_2, *and* b_3 *are regression coefficients*

Plotting truckload volume and weights for the logs indicated that volumes of individual truckloads may vary considerably for given truckload weight (figs. 4-6). The 95 confidence interval for individual loads of 60,000 pounds ranged from approximately 670 to 850 CF-VOL for the Ridge Timber Sale and 780 to 890 CF-VOL for the Board Timber Sale.

A preliminary estimate of the number of sample truckloads to achieve specified precision of sale-wide estimates can be estimated at the start of the sale using coefficients of variation developed from data in this report. Sampling can begin based on this estimate. The number of sample truckloads should be recalculated based on sale data after a representative number of truckloads have been sampled. The number of truckloads required in the sample can be calculated as follows:

$$n = \frac{1}{\left(\frac{PE}{CV}\right)^2 \left(\frac{1}{t^2}\right) + \frac{1}{N}}$$

where:

n = number of truckloads in the sample

N = estimated total truckloads in sale

PE = $(E/\bar{x}) \times 100\%$ = allowable percent error in sale-wide estimates

CV = $s/\bar{x} \times 100\%$ = estimated percent coefficient of variation

= mean of ratios in cubic feet of wood per pound of wood and bark

s = truckload standard deviation

t = Student's t value with n-1 d.f; for n larger than 25, t = 2 for P = .95

E = half the width of the desired confidence interval (i.e., the precision for the sample estimate of the mean in cubic feet of wood per pound of wood and bark)

The following steps illustrate the sample size computation:

1. Estimate the average truckload ratio weight in cubic feet per pound of wood and bark from experience or presale sample. The mean $(\bar{x})$ truckload ratio-weight = .0126 cubic feet per pound.

2. Estimate truckload ratio standard deviation from s = truckload standard deviation = .0007 cubic feet per pound.

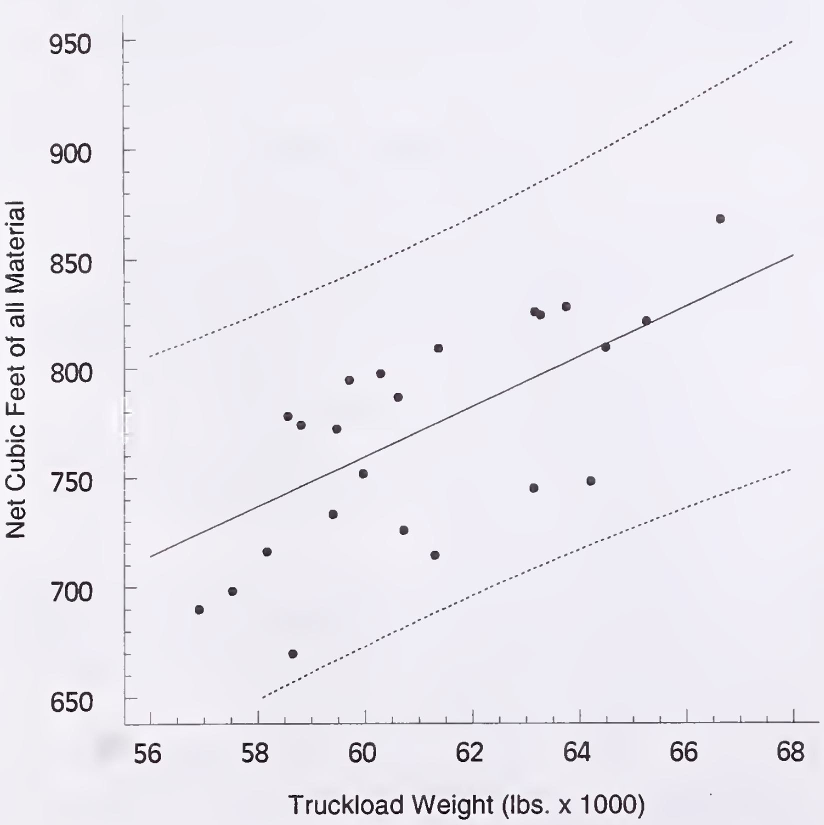

Figure 5. Scatter diagram, regression line, and P=0.95 prediction interval for single observation of net cubic feet of all material versus truckload weights for the Ridge Timber Sale.

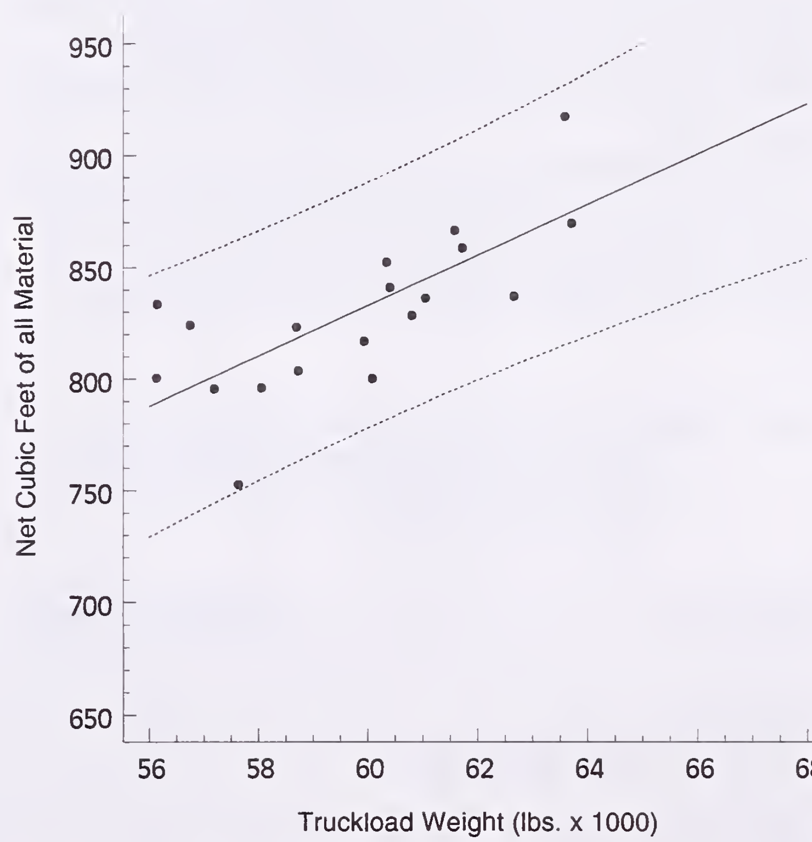

Figure 6. Scatter diagram, regression line, and P=0.95 prediction interval for a single observation of net cubic feet of all material versus truckload weights for the Board Timber Sale.

3. Compute estimated percent coefficient of variation by dividing s by $\tilde{x}$.

$$cv = \frac{s}{\tilde{x}} \times 100\% = \frac{.0007}{.0126} \times 100 = 5.56$$

4. Allowable percent error in sale-wide estimate given at 2%; PE=2%.

5. Estimate the total number of truckloads in the sale (N) when the estimated total sale cruise volume equals 208,000 cubic feet and average truckload size equals 770 cubic feet.

$$N \doteq \frac{208000}{770} 270 \text{ loads}$$

6. Substituting the above quantities and determining the proper degrees of freedom for the t value from trial and error, the number of truckloads to sample (n) was calculated as follows:

$$n = \frac{1}{\left(\frac{2}{5.56}\right)^2 \left(\frac{1}{(2.052)^2}\right) + \frac{1}{270}} = 29.04$$

The minimum number of truckloads to sample using the next higher number was 30. Table 4 shows the minimum number of truckloads of logs sampled allowing a 2% error for 3-P cubic foot scaling and 3-P Scribner board foot scaling on the 2 timber sales.

The allowable error of 2% signifies the following in terms of value to buyers and sellers. The truckloads containing 61,000 pound of greenwood and bark would average 770 cubic feet in the application example. The mean volume of wood on these truckloads would range from 754.6 to 785.4 cubic feet assuming a 2% allowable error at the 95% confidence level. The stumpage value of wood per truckload would be $693.00 assuming wood to be $90.00 per 100 cubic feet. The mean values of the same truckloads based on cubic-value measurements could range from $679.14 to $706.86.

Table 4. Minimum number of truckloads of logs to be samples allowing a 2 percent error for cubic foot scaling and Scribner board foot scaling on two timber sales.[1]

Timber sale	Number of loads
Ridge Sale	
Cubic Foot Scaling	30
Scribner Board Foot Scaling	95
Board Sale	
Cubic Foot Scaling	10
Scribner Board Foot Scaling	18

[1] *Computation of the minimum number of truckloads was based on a total timber volume of 270 truckloads for Ridge Timber Sale and 98 for the Board Timber Sale.*

CONCLUSION

Three-P cubic foot/weight scaling of ponderosa pine and white spruce estimated 44 to 68% fewer truckloads to be scaled as compared with 3-P Scribner board foot/weight scaling for two timber sales. This reduction in number of truckloads sampled reduces scaling time and costs.

This study showed that ratio weights needed to be recalculated depending upon the timber sale. Other possible sources of variation not measured in this study were seasonal variation in moisture content, site related factors, and storage in the woods (Donnelly et al. 1977, Landt and Woodfin 1959, Markstrom et al. 1982, Markstrom and King 1993, Myers 1960, Yerkes 1967). Consequently, the number of sample truckloads from a sale area should be based on sales data from that area.

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